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The long term objective of the program is to develop predictive technologies to support virtual design and evaulation of underwater vehicles systems. CFD technologies will be used to preduct hydridynamic models for AUVs and those models will be coupled with control system design and modeling tools to allow vehicle conceptual design to be evaluated within the context of a realistic mission.

The objectives of this effort were to compare the forces and moments acting on a maneuvering AUV predicted by computational fluid dynamics (CFD) code with similar data collected aboard an operational AUV. In particular, the multi-block Navier-Stokes flow solver UNCLE (Unsteady Computational of Field Equations) was used in this effort.

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Computational Hydrodynamics and Control Modeling for Autonomous Underwater Vehicles

LONG-TERM GOALS

The long-term objective of the program is to develop predictive technologies to support virtual design and evaluation of underwater vehicles systems. CFD technologies will be used to predict hydrodynamic models for AUVs and those models will be coupled with control system design and modeling tools to allow vehicle conceptual designs to be evaluated within the context of a realistic mission.

OBJECTIVES

The objectives of this effort were to compare the forces and moments acting on a maneuvering AUV predicted by computational fluid dynamics (CFD) code with similar data collected aboard an operational AUV. In particular, the multi-block Navier-Stokes flow solver UNCLE (Unsteady Computation of Field Equations) was used in this effort.

WORK COMPLETED

The first configuration studied was the un-appended SUBOFF shape. The body is cylindrical in cross-section and has a blunted conical nose and tapered tail. A 131 x 51 x 33 C-type grid system was used to discretize the fluid domain on and around the body. In order to isolate the effects of the outer boundary, the far field boundary was placed at a distance of 15 body lengths upstream of the nose and outboard of the body. Turbulent viscous solutions were obtained for this body at angle-of-attacks ranging from zero to fifteen degrees. The Reynolds number based on the length of the hull was about 14 million. In addition to the steady angle of attack cases, a set of prescribed motion cases were run for the SUBOFF body undergoing a plunge motion. Prior to beginning the unsteady plunging motion, the numerical code was run until a steady state flow condition was modeled. The unsteady forces and moments were computed from the CFD data by integrating the predicted pressure distribution on the body.

The second body modeled was the NAVOCEANO Seahorse AUV. The shape of the body and a subset of the computational grid is shown in Figure 1. The overall body length is 28.46 ft (8.67 m), and the maximum hull diameter is 3.167 ft (0.9652 m). The shroud encloses the propulsor, which includes inlet guide vanes and rotor. The fins have an airfoil-like cross-section and are mounted in an "X" configuration. Those familiar with the vehicle will recognize that the weed-guards have not been modeled. The computational grid for this body is divided into 23 blocks containing a total of approximately 4,800,00 grid points. The maximum and minimum numbers of grid points in a block are approximately 445,000 and 37,000, respectively. In the present study, each of the blade rows are modeled using an appropriate spatially distributed body force. The image in Figure 2 shows the pressure distribution on the afterbody of the Seahorse AUV predicted for one operating condition.

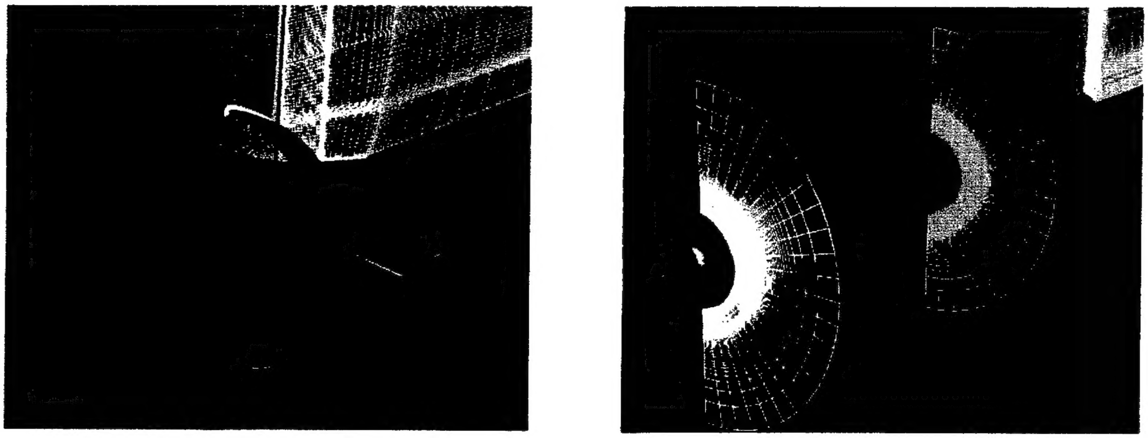

Figure 1. Seahorse AUV body and subset of computational grid used in UNCLE code.

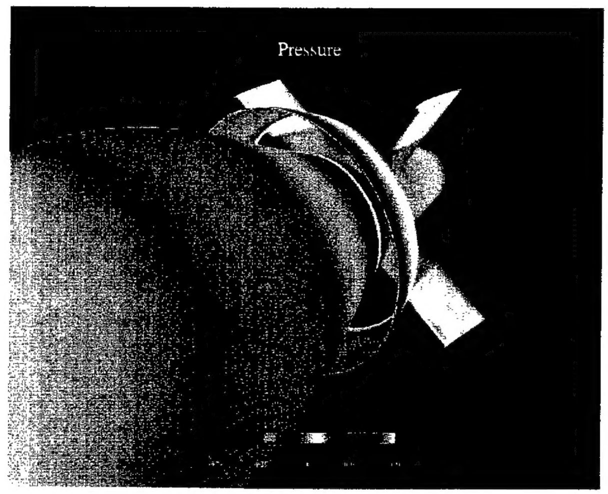

Figure 2. Predicted surface pressure distributions with body forces from propulsor model

RESULTS

The simulations conducted for the SUBOFF body were repeated for the Seahorse AUV model. Predictions for the forces and moments were obtained for steady angle-of-attack cases and for the unsteady plunging motion. Table 1 shows a subset of the linear stability derivatives predicted for the Seahorse AUV. The table shows the name of the non-dimensional coefficient in the first column, the value of the coefficient predicted by CFD calculations in the send column, the estimated value for the coefficient made during vehicle development in the third column, and a coefficient obtained from the analysis of operational data.

Table 1: Seahorse Hydrodynamic Coefficients From Measured and Predicted data.

Coefficient	CFD	Semi-empirical	Experimental
Z'_w	-0.01408	-0.0139	-0.01072
$Z'_{\dot{w}}$	-0.0218	-0.02103	
M'_w	0.00927	0.01248	0.00366
$M'_{\dot{w}}$	-0.00012	-0.000517	
$Z'_{\delta e}$	-0.0108		-0.0089
$Z'_{\delta e}$ and $Z'^{3}_{\delta e}$	-0.0063 and –0.2059	-0.0057 and 0.0074	-0.006 and –13.4
$M'_{\delta e}$	-0.0094		-0.0052
$M'_{\delta e}$ and $M'^{3}_{\delta e}$	-0.0073 and –0.0952	-0.0034 and –0.0045	-0.0082 and 0.219

Steady-state at AOA=0°,2.5°,5°,10°,15°
Steady-state at Fin AOA=0°,2°,4°,6°,8°,10°
Vertical plunge, V_∞=6.5, V_{plunge}=0.025*V_∞

Table 2: Seahorse Hydrodynamic Coefficients From Measured and Predicted data.

Coefficient	CFD	DTRC Experimental Data
Z'_w	-0.0069	-0.0059
$Z'_{\dot{w}}$	-0.0169	-0.0128
M'_w	0.0135	0.0128
$M'_{\dot{w}}$	0.00017	0.0002

Steady-state at AOA=0°,2.5°,5°
Vertical plunge, V_∞=6.5, V_{plunge}=0.025*V_∞

The coefficients Z'_w and M'_w are obtained by plotting steady-state Z (force along vehicle z axis) and M (moment about vehicle y axis), respectively, against the corresponding angles of attack, 0°,2.5°,5°,10° and 15°. The slopes of these curves about the origin yield the appropriate coefficients. $Z'_{\dot{w}}$ and $M'_{\dot{w}}$ are obtained from the CFD data for the vertical plunge, unsteady simulation. The raw CFD data is dimensionalized and a least squares fit of Z and M with w and $\dot{w}$, the velocity and acceleration along the vehicle z axis, yields $Z'_{\dot{w}}$ and $M'_{\dot{w}}$ respectively. Alternately, since Z'_w and M'_w are known from the angle of attack CFD cases outlined above, their contributions may be removed from Z and M and a least-squares fit obtained from $\dot{w}$ alone.

The elevator fin coefficients are obtained from the steady state Z and M on the body with the fins deflected at elevator angles of 0°, 2°, 4°, 6°, 8° and 10°. Force and moment contributions from the zero fin deflection, zero angle of attack simulation used above are removed from Z and M to obtain forces and moments on the vehicle due to the fins alone. Z and M are then least square fit with $u^2\delta_e$ and

$u^2\delta_e^{\ 3}$ to obtain the fin coefficients. The cubic terms are not accurate since the non-linear contribution of fin forces is apparent at higher fin deflections than those used in the CFD simulation as well as those used to experimentally determine the fin coefficients. It is, however, important to include the cubic term in the fit so as to isolate the linear term from it.

IMPACT/APPLICATIONS

The methodologies developed under this project have the potential to significantly improve the performance and reduce the cost of developing underwater vehicles. In the case of the Seahorse AUV, tow tank testing would have added an additional $300K to the overall cost of the project. The ability to predict the hydrodynamic forces and moments of large AUVs will continue to reduce the development cost of future systems through the elimination of some hydrodynamic testing.

There were neither invention disclosures nor anything of patentable nature developed under this grant.

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